Ecological Refrigerant Cascade Systems Replacement in Accordance with the EU Regulations

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Abstract. The paper analyses ecological refrigeration cascade systems in accordance with Regulation (EU) no. 517/2014 of the European Parliament and Council of 16 April 2014. In present the cascade refrigeration plants work with refrigerants R23/ R404A. In accordance with the Regulation F-gas we will replace R23(GWP=14800) refrigerant with the new refrigerant gas R472A with the lowest GWP value (GWP=353) and R404A refrigerant with R448A. The refrigerant R472A is perfectly compatible with the commercial elements used in cascade refrigeration plants charged with R23. R472A [CO2/R32/134A] refrigerant can be used for ULT (Ultra Low Temperature) applications must reach a temperature lower than or equal to -70°C. The determination of the thermodynamic properties was performed with the help of the Refprop program. The TEWI factor analysis was performed for a cascade refrigeration installation which is located in the Laboratory of the Technical University of Civil Engineering Bucharest, Thermodynamics, Heat and Mass Transfer Department.

Keywords. Refrigerant, alternative mixture**,** GWP**,** TEWI factor
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1. Introduction

In terms of global warming potential (GWP), at international level regarding the refrigerants, according with the new legislative Regulations [1] ecological alternatives must be founded for refrigeration systems and in this article was studied the case of a testing room, which is located in the Laboratory of the Technical University of Civil Engineering Bucharest, Thermodynamics, Heat and Mass Transfer Department.

Global warming and ozone depletion are two separate environmental problems, but in the end, they are in connection.

The testing room presented in this paper works with a cascade refrigeration system and R23/ R404A refrigerants.

The technology used in the design of this testing room includes thermal insulation materials, super-efficient cooling systems and PC-based control using the powerful WINKRATOS® software package.

2. Ecological Analysis

In accordance with the F-Gas Regulation were replaced R23 and R404A [HFC-125/HFC-143a/HFC-134a] refrigerants with new refrigerant R472A[CO2/R32/134A] and the refrigerant R448A [R32/R125/R134a/R1234ze/R1234yf] with lower GWP values (see table1).

The mixture refrigerant R472A is perfectly compatible with the commercial elements used in cascade refrigeration plants charged with R23 refrigerant.

This refrigerant (R-472A) with low global warming potential (GWP) replace R404A in positive displacement, direct expansion low and medium temperature commercial and industrial applications.

R472A [CO2/R32/134A] refrigerant can be used for ULT (Ultra Low Temperature) applications which must reach a temperature lower than or equal to -75°C.

R448A is an azeotropic blend, which is classified as a non-flammable replacement refrigerant with a low GWP value. It was designed to serve as a replacement for R404A (and R22) in low and medium temperature systems.

The thermodynamic properties (Fig.1, Fig.2 and Fig.3) were determined with the Refprop [2] software.

Table 1 presents some properties of the refrigerant used in this cascade refrigeration system.

Tab. 1 - Comparison between ecological alternatives for the testing room [1,2,3,4,5].

Refrigerant	R404A	R448A	R23	R472A
Safety group	A1	A1	A1	A1
Critical temperature [°C]	72.04	83.65	26.14	44.46
Critical pressure [bar]	37.28	44.95	48.32	68.43
Critical density [kg/m3]	486.54	480.17	526.5	466.17
Molar mass [kg/kmol]	97.60	86.28	70	50.38
ODP	0	0	0	0
GWP	3922	1387	14800	353

Figure 1 presents a thermodynamic comparison between the properties of refrigerants. The pressure evolution vs temperature after simulations of the refrigerants R404A, R23, R472A and R448A can be observed.

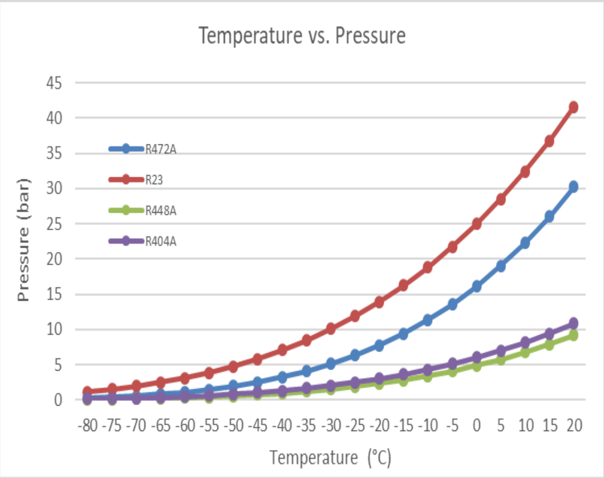

Fig. 1 – Temperature vs. pressure

In the Figure 2 and figure 3 are shown the comparisons between the density and enthalpy in vapour phase for the proposed refrigerants R404A, R472A, R448A and R23.

Some advantages of the new refrigerant R472A are presented. Thanks to miscibility refrigerant R472A is the only gas that makes it possible to use the gas bottle even partially, always ensuring the homogeneity of the mixture both inside the refrigerating plant and in the gas. Quantity remained in the bottle, being reusable in the future.

This is a great advantage for the technicians and students who work with R472A in the laboratory, since they can manage the gas bottles in an extremely easy and safe way, as it is normally the case for other gases commonly used in refrigeration, such as R449A or R452A [9].

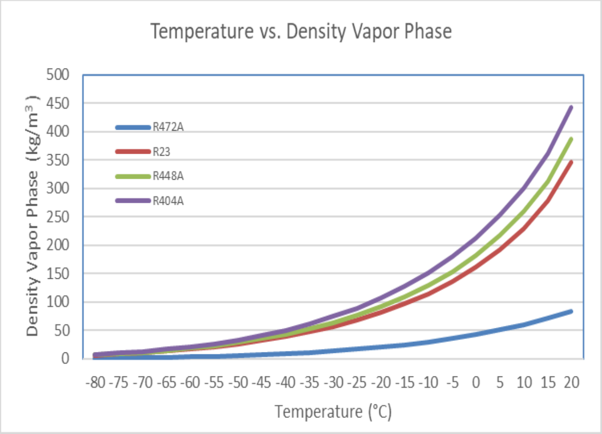

Fig. 2 - Temperature vs. density vapour phase

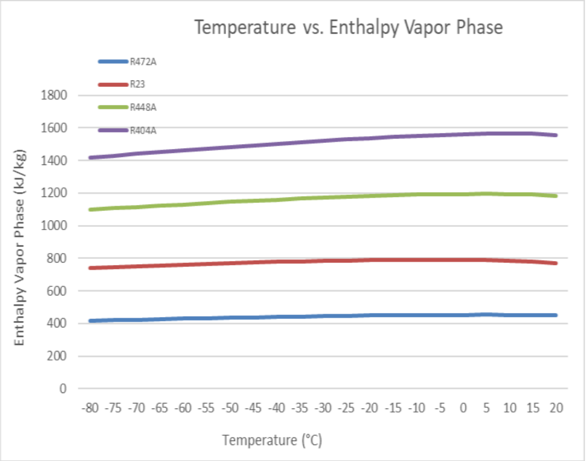

Fig. 3 - Temperature vs. enthalpy vapour phase

R472A is non-flammable and non-toxic: it has obtained the A1 Safety Class by ASHRAE (the American Society of Heating, Refrigerating and Air Conditioning Engineers). Another advantage of this fluid is that R472A has the lowest density vapor phase in comparison with the other refrigerants (Fig.2).

3. Theoretical Study Case

The theoretical comparative study was done for the testing room in a cascade refrigeration system.

The system is loaded with ozone harmless fluids: R404A and R23 but which are in conflict with F-Gas Regulation refrigerants and are not allowed to be used in new refrigeration systems and are strongly restricted.

The testing room has 1200l useful capacity. The environmental humidity and temperature test chamber has an operating temperature range between -70° C and +180°C.

The testing room environmental chambers, continuously improved and up-to date with the latest technologies. Designed to meet the increasingly sophisticated quality and reliability requirements of the humidity and temperature testing chambers [5,6].

The challenge family of chambers always offers superior performances and a striking "high tech" look. The cooling system has been optimized to give maximum thermodynamically efficiency and an accurate temperature control.

Cooling is obtained by the evaporation of the liquid injected into the evaporator.

The compressor compresses the gas refrigerant and after that into the condenser under the effect of the high pressure the cooling gas changes state and becomes liquid. The liquid expands thanks to a thermostatic valve and as it evaporates, it absorbs heat and induces cooling at the same time.

The cycle is completed when the gas is sucked in once again by the compressor.

This cascade refrigeration plants use semi hermetic compressors which are compatible with the characteristics of new refrigerants and the demands of the market related to efficiency, reliability and low noise level [7,8,9].

The characteristics of the compressors are: high C.O.P. values, thanks to fluid dynamic optimisation of the internal flow paths, high efficiency motors and high-tech components, low vibrations and low gas pulsation.

The TEWI factor was calculated in according with UE legislation.

The total global warming potential method calculation (GWP) of Ecological Alternative was done in according with REGULATION (EC) No 842/2006 (from 1 January 2015 REGULATION (EC) No 517/2014).

To calculate TEWI factor were following assumptions: mass of refrigerants made seen in Figure 4.

The leakage of refrigerant was 8% from refrigerant charge with a recovery factor of 0.75. Operating time of the system was 15 years, and CO2 emission was 0,28985 kg / kWh for country where the system is located (Romania).

The TEWI factor was determinate [10,11] taking account of the Standard EN 378-1:

$$TEWI = [GWPx\ Lxn] + [GWPx\ mx(1-\alpha_{rec})] + [nx\ E_{annual}\ x\beta] \quad (1)$$

Where:

GWP – the global warming potential, CO_2related

L – leakage in kilogrammes per year

n – system operating time in years,

m – refrigerant charge in kilogrammes

α_{rec} - recovery/recycling factor from 0 to 1

E_{annual} – energy consumption in kilowatt-hour per year

β - CO_2 emission in kilogrammes per kilowatt-hour kg/kWh

$[GWP\ x\ m\ x\ (1-\alpha_{rec})]$ - impact of recovery losses

$[GWP\ x\ L\ x\ n]$ - impact of leakage losses

$[n\ x\ E_{annual}\ x\ \beta]$ - impact of energy consumption.

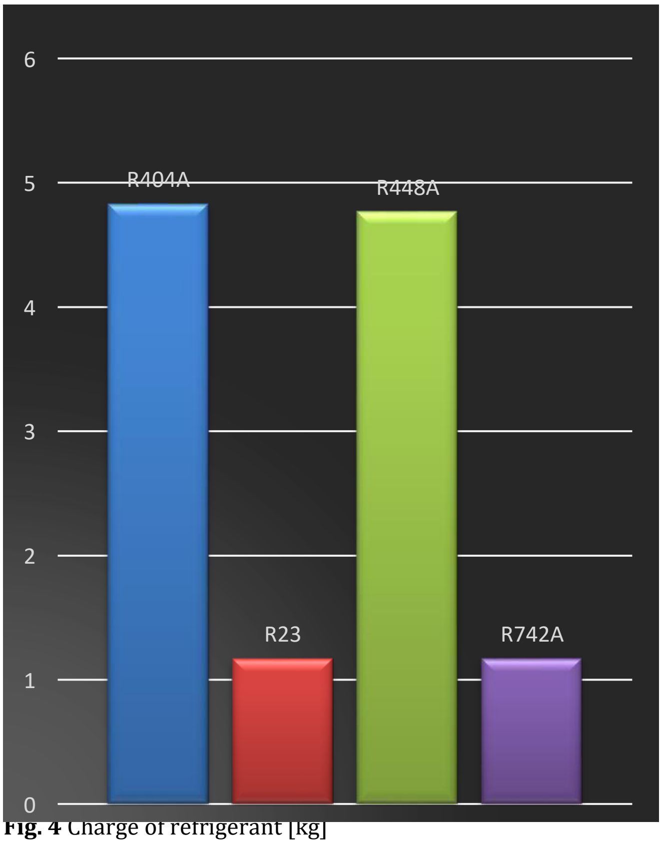

Fig. 4 Charge of refrigerant [kg]

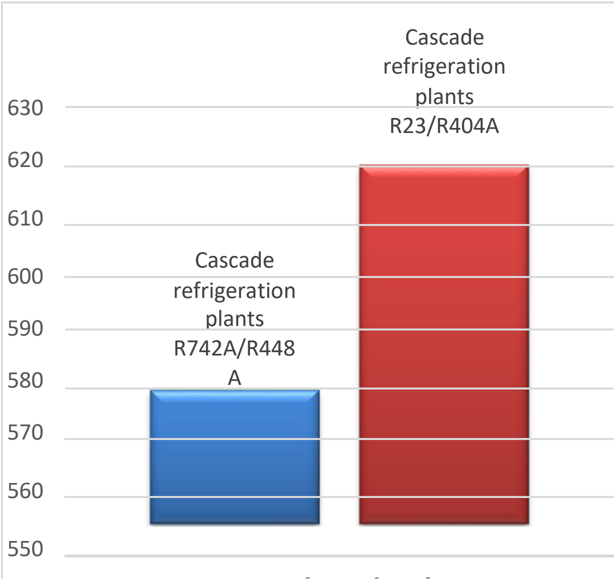

Fig. 5 Comparison of TEWI factor between cascade refrigeration R404A/R23 and R742A/R448A

Higher performance is highlighted when R742A/R448A is used - the reduced amount of refrigerant, a feature with environmental benefits reflected by the TEWI equivalent (Total Equivalent Warming Impact) as it is shown in figure 5.

In the cascade systems, the contribution to warming the atmosphere is both direct (due to the refrigerant) and indirect (through the energy used), the second being the most important [12].

4. Conclusions

Regarding F-Gas Regulation [1], the optimum alternative for this application (testing room with cascade refrigeration plant) from the point of GWP is refrigerant mixture R472A/R448A.

After determinations of the thermodynamic properties, it could be observed (Fig. 1) that the alternative R448A is the best option in comparison with refrigerant R404A because pressure is much lower for temperatures between -70°C ÷ +40 °C.

Also, alternative R472A has the lowest density vapor phase in comparison with the other refrigerants (Fig.2).

From an environmental perspective of lower global warming potential (GWP) alternative R472A has the advantage of 77% lower global warming potential (GWP) than R23.

The molar mass of the alternative 472A has an advantage because it is lower than R23 (Tab. 1)

From an environmental point of view, the theoretical results of the R472A/R448A cascade system have the best TEWI = 575,78 tons of CO2, 7% lower than R404A/R23 (Fig.5).

5. References

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